

INTERPLAY BETWEEN PERIODIC, CYCLIC AND STOCHASTIC VARIABILITY
 IN SELECTED AREAS OF THE HR DIAGRAM
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A warped accretion disc in PX And ?

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Abstract. We have undertaken a photometric study of the SW Sex star, PX And. We clearly identify a negative superhump signal which might be regarded as the signature of a nodal precessing disc, possibly warped. PX And is also observed to possess highly variable eclipse depth and we discuss two possible explanations.

1. Introduction

PX And is probably one of the most complicated SW Sex stars. Thorstensen et al. (1991) reported shallow eclipses with highly variable eclipse depth and repeating with a period of $\sim 0^d.1463533$. Assuming a steady-state accretion disc and $q \simeq 0.46$, and fitting a mean eclipse, they obtained $i \simeq 73.8^\circ$ and $r_d \simeq 0.6R_{L1}$. Apart from the distinctive characteristics of SW Sex stars (Hellier 2000), PX And shows some other interesting peculiarities. Patterson (1999) reported PX And to show simultaneously “negative” and “positive” superhumps, and signals with typical periods of 4–5 days. With $q \simeq 0.46$, i.e. above the canonical 0.33 value where the 3:1 resonance still lies inside the Roche lobe, it is not clear however how PX And could show positive superhumps.

We have undertaken a photometric study of PX And. In total 8 runs were obtained in 2000 and 2001, with the 2.0-m telescope of Rozhen Observatory, in the Johnson *V* filter. The exposure time used was between 20 and 40 s. In addition, two unfiltered runs were obtained with the 1-m telescope at Hoher List Observatory. A detailed description of these observations, in which we clearly identify a negative superhump signal and its associated precession period, are presented in Stanishev et al. (2002). Here, we will briefly summarize our results and then discuss them in light of the warped precessing disc model.

2. Results

From our five photometric runs in October 2000, the following periods were determined: $P_{\text{SH}} = 0^d.142 \pm 0.002$, $P_1 = 0^d.207 \pm 0.004$ and $P_{\text{prec}} = 4^d.8$ with semi-amplitudes of 0.086, 0.076 and 0.256 mag, respectively. The light curves as well as our fit to the data is shown in Fig. 1a. Our observations also show that the star presents eclipses whose depth is modulated with the 5-days period (Fig.

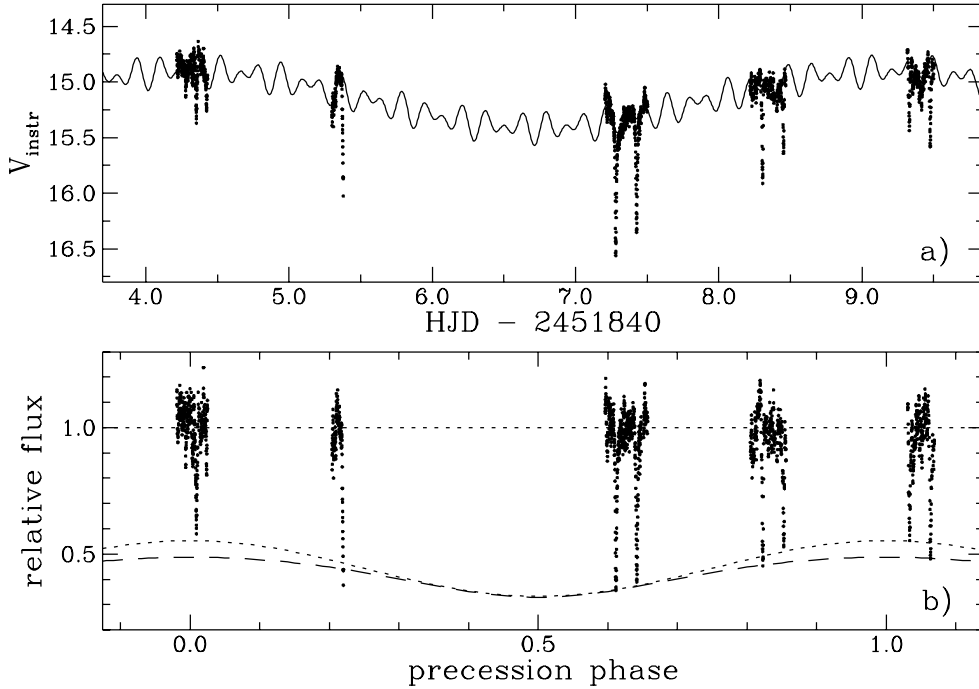


Figure 1. *Upper row:* V band observations of PX And and the best fit with the detected periods. *Lower row:* The same data, but with the best fit subtracted and displayed in flux scale. The fit to the eclipse depths is also shown (dotted line) as well as the result of a simple model for the eclipse of a warping disc (dashed line; see Sect. 4.2).

1b). The best fit to the depths of the eclipse is shown with a dotted line in Fig. 1b. The mean eclipse depth is ~ 0.56 (~ 0.89 mag) and the amplitude of the variation is ~ 0.22 .

For the three runs obtained in 2001, we obtain a strong peak, corresponding to a “negative superhump” with $P_{\text{SH}}^- \simeq 0^{\text{d}}.141$. This value of P_{SH}^- gives $P_{\text{prec}} \simeq 3^{\text{d}}.8$. The corresponding semi-amplitudes are 0.069 and 0.21 mag. The $0^{\text{d}}.207$ period is not detected in 2001.

3. Negative superhumps

The origin of the “negative superhumps” is still an open question. The most plausible model is based on the assumption of a retrograde precession of a tilted accretion disc. However, all attempts to simulate “negative superhumps” failed in the sense that they were not able to produce a significant tilt starting from a disc lying in the orbital plane (Murray & Armitage 1998; Wood, Montgomery, & Simpson 2000). The only exception we are aware of, is the recent work of Murray et al. (2002). Once tilted, however, the accretion disc starts precess-

ing in retrograde direction (Larwood et al. 1996; Wood et al. 2000). Taking into account foreshortening and limb-darkening, one can estimate the disc tilt needed to produce the observed amplitude of the 4^d8 modulation in PX And. With a limb-darkening coefficient $u = 0.6$ the tilt angle is between 2.5° and 3° , depending on the assumed system inclination.

The mechanism generating the “negative superhump” light itself is however rather uncertain. According to the simulations of Wood et al. (2000) the two opposite parts of the disc which are most displaced from the orbital plane are tidally heated by the secondary. The heating is maximal when these parts point to the secondary and this happens twice per superhump cycle. Figure 2 shows a sketch of the system configuration in eclipse at $\phi_{\text{prec}} = 0.13$, that is, when the maxima of the superhumps coincide with the eclipses. The expected position of the superhump light source (SLS) according to Wood et al. (2000) and the line of nodes are also shown. The dashed line marks the part of the disc which lays below the orbital plane.

There is another mechanism which could generate “negative superhumps”. Patterson (1999) noticed that most of the SW Sex novalikes show “negative superhumps” and this could naturally be explained by the accretion stream overflow thought to be responsible for the SW Sex phenomenon (Hellier & Robinson 1994). In a system with a precessing tilted accretion disc, the amount of gas in the overflowing stream will vary with the “negative superhumps” period. Correspondingly, the intensity of the spot (shown in Fig. 2) formed where the overflowing stream re-impacts the disc should be modulated and might be the “negative” SLS.

In fact, stream overflow might even not be necessary. Indeed, if the disc is precessing out of the orbital plane, the “hot spot” (i.e. the place where the L1 stream hits the accretion disc) will be at a different location during the precession cycle. When the disc is out of the plane, the hot spot will be closer to the white dwarf than when the disc is in the plane. Thus the amount of gravitational energy which will be converted partly in radiation at the hot spot will vary with the precession phase, and this could create a modulation. Such a model was already proposed for the intermediate polar TV Col by Barrett, O’Donoghue, & Warner (1988).

4. Eclipse depth variations

The most puzzling observation of PX And is its highly variable eclipse depth. Our observations suggest that the eclipse depth is modulated with the precession period (Fig. 1), indicating that this phenomenon could be related to the disc precession. We will discuss two ways to modulate the fraction of the eclipsed light with the precession period and hence the eclipse depth.

4.1. Veiling by superhumps light source

If the SLS is never eclipsed, the eclipse depth will be affected in a way analogous to the *veiling* of the absorption lines in T Tau stars, where the additional emission in the continuum reduces the observed depth of the absorption lines. The eclipse depth will depend on the fraction of superhump light at the moment of eclipses, being least when superhump maxima coincide with the eclipses. At the moments

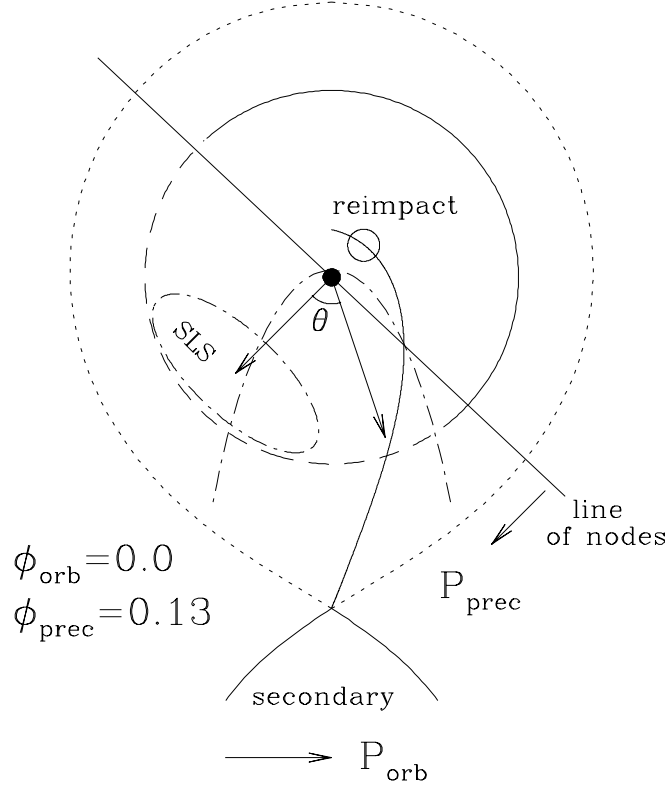


Figure 2. A sketch of the system configuration at $\phi_{\text{prec}}=0.13$ and $\phi_{\text{orb}}=0$. The disc edge marked with the dashed line lays below the orbital plane. Also shown are the expected position of the SLS, shadow of the secondary, accretion stream and re-impact zone.

of eclipses, the superhump flux varies with the precession period and therefore an eclipse depth modulation with the 5-days period will be observed. If F_{mod} is the superhump flux and F_{const} is the accretion disc flux, then the equation

$$d_e = \frac{d_{e,0}}{1 + F_{\text{mod}}/F_{\text{const}}} \quad (1)$$

gives the eclipse depth as a function of the additional modulated light in the case when this light is not eclipsed. Here, $d_{e,0}$ is the eclipse depth if $F_{\text{mod}} = 0$. At maximum the SLS in PX And contributes $\sim 17\%$ to the total system light, which means it could decrease the eclipse by only ~ 0.1 . This is only a half of the observed modulation.

If we assume that the modulation is simply due to the fact that the position of the hot spot will change as a function of the precession phase, as described at the end of Sect. 3., things become a little bit more complicated than this

simple model. Indeed, when the disc is most inclined, then the hot spot might not be eclipsed, while it could be eclipsed when the disc is in the orbital plane. Moreover, the intensity of the spot will vary depending on its location. This might well increase the amplitude of the modulation to the observed value.

4.2. Warped accretion disc in PX And?

Let us assume that only part of the total light emitted by the disc is modulated with the precession period. Then, if the unmodulated light is totally eclipsed while the modulated light is only partially, the eclipse depth will vary because a different fraction of the total light emitted by the system will be eclipsed at different precession phases. The deepest eclipses are expected at the precession cycle minima, as observed. The relatively shallow eclipses show that the accretion disc in PX And is not totally eclipsed. Then, since the constant light source must be eclipsed, its most likely location is close to the white dwarf with the most obvious candidate being the inner hot part of the disc. However, since the brightness modulation with the precession cycle comes from more or less pure geometrical considerations (precession of a tiled disc) it is not clear why the emission of the inner parts of the disc could be constant. One possible explanation might be that only the outer disc part is tilted, while the inner part of the disc is not tilted. This means that the disc is *warped* rather than simply tilted. In this case the emission from the inner disc will be constant and only the rest will be involved in the 5-days modulation. Generally, disc warping is not considered with respect to CVs. Very recently, however, Murray et al. (2002) recognized the potential role of the magnetic field of the secondary as a source of warping in CVs accretion discs. Murray et al. have shown that the magnetic field of the secondary can drive the disc out of the orbital plane and warp it. As a consequence the disc starts precessing in retrograde direction, exactly as is needed to generate "negative superhumps".

Let us consider the following simple model, which should approximately represent the eclipse of a warped disc. The emission from the inner part of the disc which contributes a fraction α ($0 < \alpha < 1$) of the total light is held constant, while the rest $1 - \alpha$ is modulated so as to produce the observed amplitude of the 5-days wave. The constant light is considered to be totally eclipsed and only a fraction γ ($0 < \gamma < 1$) of the modulated part is eclipsed. The dashed line in Fig. 1b is calculated with $\alpha = 0.35$ and $\gamma = 0.25$; this should, however, not be regarded as a fit, but only as a demonstration of the capability of the model to produce eclipse depth variations. A value of $\gamma = 0.25$ corresponds approximately to what is observed in a system with $q \simeq 0.3 - 0.4$ and an inclination such as the whole inner part of the disc is totally eclipsed. This simple model gives an eclipse depth modulation of ~ 0.16 , which is closer to what is observed in PX And. To produce the observed amplitude of the 5-days wave the flux from the outer disc part should be reduced by $\sim 58\%$. With a system inclination $\sim 74^\circ$, this is achieved by wobbling the disc by $\pm 4^\circ$, if only the foreshortening is taken into account.

4.3. Concluding remarks

It seems that the two models have difficulties to explain the observed amplitude of the eclipse depth modulation. In spite of these difficulties we consider our

results as a step ahead. Thorstensen et al. (1991) could produce eclipse depth variations only by changing the secondary radius by $\sim 5\%$, but as they noted this is clearly physically unreasonable.

If the first model discussed is responsible for the eclipse depth modulation then the stream overflow is more likely to be the mechanism generating the “negative superhumps” in PX And. This is because in a system with grazing eclipses the re-impact zone is not eclipsed, while the SLS in the model of Wood et al. (2000) should be at least partially eclipsed.

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